Efficient Hybrid Energy Harvesting for WSN Application

SHORT SYNOPSIS

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by

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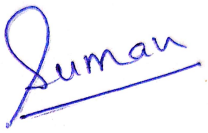
Certificate

I hereby declare that the short synopsis "Efficient Hybrid Energy Harvesting for WSN Application"being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in electronics and communication under faculty of Engineering and Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2020.

It is a bona fide record of original work carried out under the supervision of Prof.(Dr.) Geeta Nijhawan and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.



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ABSTRACT

Wireless Sensor Network (WSN) is the most important network in the world next to internet due to its wide range of application. Life time of the sensor node is limiting factor which need to improve in the mission critical and environmental application where human intervention is next to impossible. Changing batteries of the sensor node for the maintenance may be very harmful for the human life and also very costly for the geographical areas like glaciers and volcanoes. Hybrid energy harvesting is a concept applied for improving the performance of the conventional stand-alone energy harvesters. An investigation of the current issues of the energy harvesting and hybrid energy harvesting has been done by reviewing the existing work. The survey shows that there is still a research gap in finding new framework of the hybrid energy harvesting methods. Integration of hybrid energy system is the important issue which is needed to encounter in the future work. The efficient buck/boost converters for the hybrid energy harvesting and efficient Maximum Power Point Tracking (MPPT) are still a challenge. On the base of the existing work unattended areas of hybrid energy harvesting in the form of optimization of framework has been found. Some of the issues related to algorithm for different kind of hybrid energy harvesting systems which work along with the algorithms of WSN node is found as research gap. This is found that the many energy harvesting techniques are getting combined to achieve the goal of perpetual life time of the Wireless Sensor Network (WSN) node. The prime aim is to search in analytical formulations and characterization of a hybrid energy harvester that incorporates photovoltaic, piezoelectric, electromagnetic, and electrostatic mechanisms. The characteristic parameter is modeled by MATLAB. The proposed framework will be used to enhance the lifetime of the sensor node and to power the low power battery operated devices. Investigation of effectual efficiency, frequency range, energy consumption and reliability of the proposed hybrid energy harvesting system will be the outcome the research work. Network lifetime can be maximizing by considering optimized hybrid energy harvesting system. The captured energy can be stored in the rechargeable storage unit and hence the period of operation of sensor node can be increased. Optimal energy harvesting is basically the technique by which the energy in the nodes can be increased by harvesting energy from natural sources by using the best energy harvesting method and getting best outputs.

Keywords Hybrid Energy Harvester, photovoltaic, piezoelectricity, electromagnetism, electrostatic mechanism, Solar energy, Wireless Sensor Network (WSN), Sensor Node, MICA mote.

1. INTRODUCTION

Wireless Sensor Network (WSN) is made of little electronic nodes equipped with sensor, microcontroller and ability to communicate with the surrounding nodes using ZIGBEE (802.15.4) protocol.

All the things are under operation only due to energy source battery. Battery defines the time of operation of sensor node. Depletion of battery stops the activities of senor node and the network performance get compromised. Energy harvesting is the mechanism through which the energy in nodes can be increased by harvesting energy from natural sources like Solar, thermal, wind, mechanical etc. The time period of sensor nodes can be increased by storing the captured energy in rechargeable storage unit and hence then period of operation of sensor node can be increased.

Single energy harvesting technique may not provide proper energy to the sensor node and sensor node life time may be compromised. More than one energy source may provide the perpetual life time to the sensor network. In this section, there is discussion about the WSN node, lifetime and a brief introduction about the architecture of energy harvesting.

1.1 Wireless Sensor Networks

Wireless Sensor Networks (WSNs) are configured on their own and are infrastructure-less wireless networks of physically distributed sensor nodes, to analyze and record of environmental and physical real time values, e.g. sound, temperature, pressure, vibration, pollutants etc. They can collectively pass the information across the established network to base station. The information collected is analyzed and observed at base station. A wireless sensor node is usually equipped with devices that sense and compute, radio transceivers and power components by which they can send radio signals between each other. The various applications of WSNs can be military application, area monitoring, transportation, health applications, environmental sensing, structural monitoring, industrial monitoring and agricultural sector. Figure 1 depicts the traditional architecture of WSN.

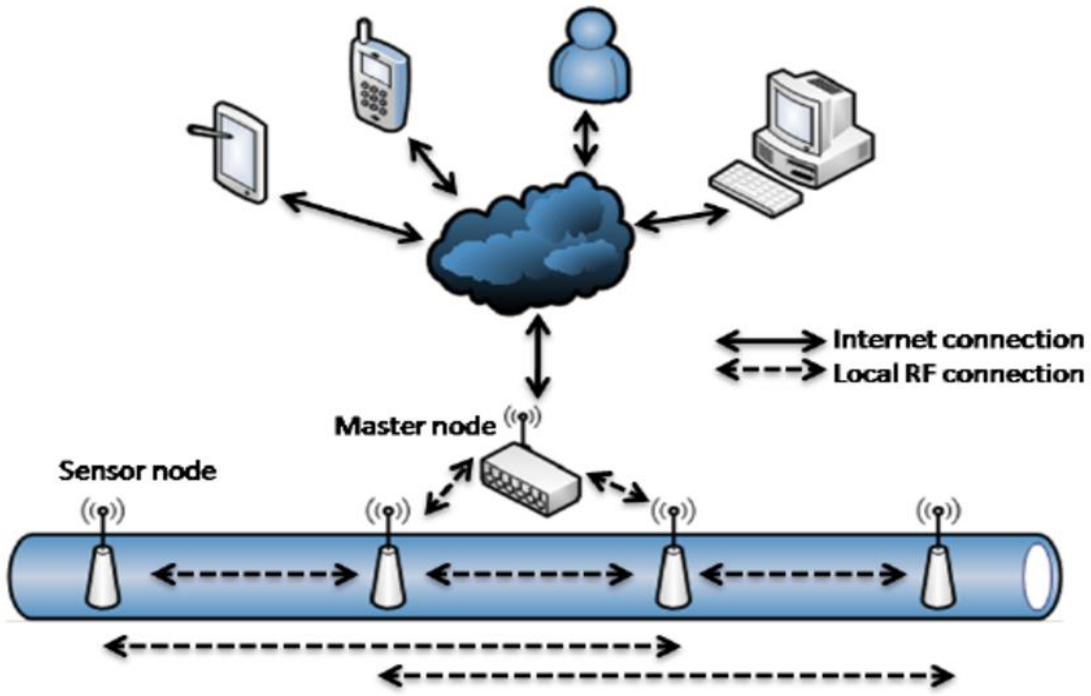

Figure 1: Architecture of WSN

1.2 Life time of Sensor Node

This is the duration of the wireless sensor network from starting the fully functional network to when the first node die. This is also known as Network's time span. In terms of hardware of single node, the duration for which the battery of single node depleted and it is unable to participate in networking, the node is said to be inactive.

1.3 Energy Harvesting And Its Types

Various energy harvesting systems are discussed below. Figure 2 shows the basic architecture of node with energy harvesting mechanism (Power Generator).

1.3.1 Solar Energy Harvesting Solar radiation is changed into electrical energy using solar cell or photovoltaic (PV) cell. Solar cell provide output electrical energy and the energy is captured in battery or any energy storage devices.

1.3.2 Wind Energy Harvesting Wind energy is converted into kinetic energy and this kinetic energy forces the propellers or diaphragm which connected to moving coil under static magnetic

field. This arrangement forces the design to generate the electrical output energy. For small scale energy harvesting, the wind energy still has challenges.

1.3.3 Thermal Energy Harvesting The thermal energy may be due to greenhouse effect due to the gases in environment like CO_2, H_2O, CH_4, etc. or due to manmade heat energy sources like boilers, engines etc. Temperature difference across thermoelectric material provides output electrical power. In this case, the output power is straightly corresponding to the temperature gradient over the thermoelectric generator and figure of merit of thermoelectric material.

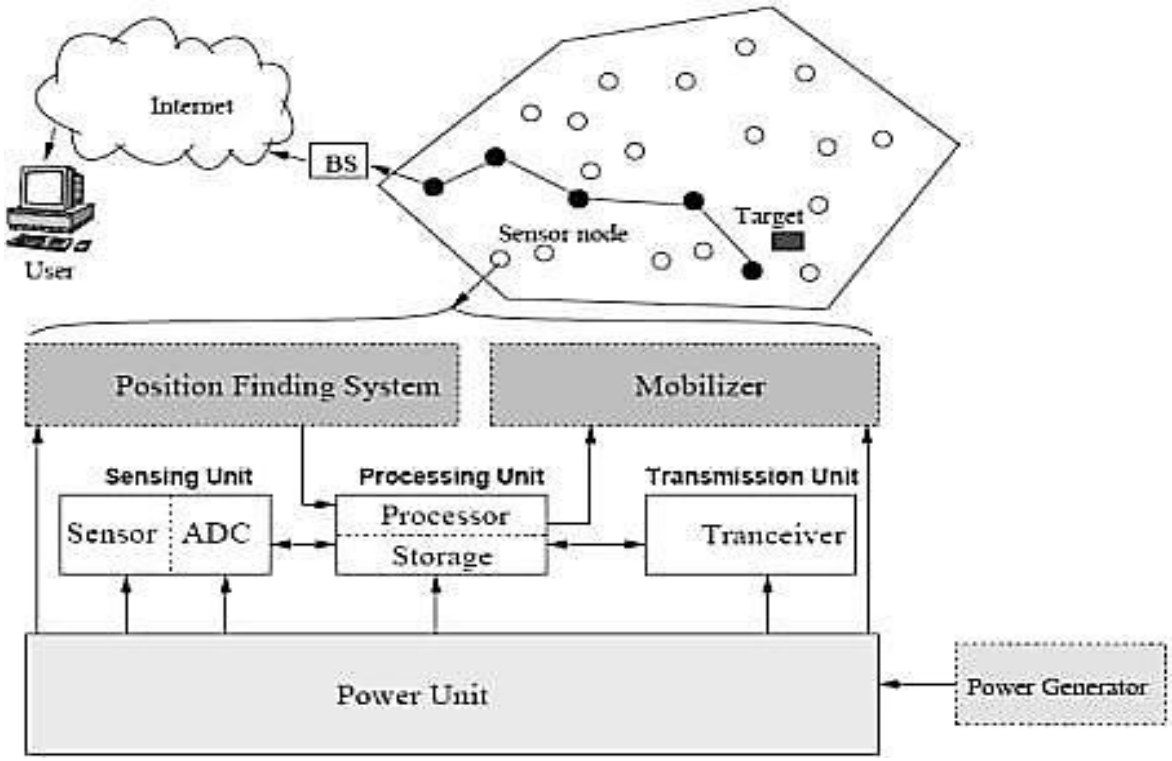

Figure 2: Basic architecture of energy harvesting mechanism

1.3.4 Energy Harvesting Using Liquid Displacement Liquid (e.g. water, oil, sea water etc.) with velocity, acceleration, force or pressure can provide kinetic energy which further can be utilized to move any coil with static magnetic field and this can be utilized to make electrical energy which can power mini electronics.

1.3.5 Acoustic Energy Harvesting Vibrations in liquids, solids or in gases can be used to provide vibrations in the diaphragm which further can be utilized for the energy generation.

1.4 Role of Hybrid Energy Harvesting (HEH)

Now-a-days, the interest in harvesting energy from the environment is increasing rapidly. Harvested energy from the ambient sources (usually at micro level) can be used to – (a) power MEMS and WSNs, (b) replace batteries in MEMS and WSNs (c) recharge batteries and capacitors, and (d) increase lifespan of the power supply.

2. LITERATURE REVIEW

Harvesting energy from the environment forces the researchers to investigate over the various architectures and framework by which very small scale energy harvesting system can be generated which can be used in WSN node types of small scale electronics. Research community is developing architecture for the solar energy vibration energy or mechanical energy, wind energy and RF energy harvesting. Various challenges associated with the energy harvesting for the WSN is discussed and analyzed in this section. There are many theories proposed on this. Although this literature review covers a wide variety of such theories but which emerge repeatedly throughout the review are solar and thermal energy.

Rahman and Chakravarty (2018), proposed hybrid energy harvesting by means of solar and vibration by combined structure of the piezoelectric, photovoltaic, electromagnetic mechanisms and electrostatic. This allows a developed model of hybrid energy harvesting which can provide stagnant supply to low power and small scale electronics without failure. It also provides small scale hybrid design for energy harvesting to obtain energy for wireless sensor network system. Reciprocal interactions and buffering mechanism effect, they are not considered as a way to avoid the complexity of the analysis. The analysis for the hybrid structure shows agreement with the finite component analysis result. The theoretical analysis of the proposed model still needs the implement at hardware level so that validation can be done properly.

Zulkifli, Sampe, Semsudin, et. al.(2017) confirmed the study which uses radio frequency (RF), thermal and vibration for energy harvesting system in biomedical devices. These energy inputs may be obtained from human's environment and his surroundings. Voltage summer circuit is used to combine all the input energies. PSPICE software is used for circuit designing and implementation. Proposed circuit is implemented by PCB for combination of vibration and thermal. For resistive load of 1 ohm, the system gave output voltage of approximately 2.8V. The energy harvested can be enhanced by using the intelligent algorithm which could be implemented in the next research work.

Ulusan, Chamanian, Pathirana et. al. (2016) developed energy harvesting system which produce hybrid power from vibration-based electromagnetic (EM), (PZT) and thermoelectric (TE) harvesters for a peak energy supply ability. The vibrations with low frequency are harvested using electromagnetic harvester and rectified by a passive rectifier whereas vibrations with high frequencies are harvested by piezoelectric harvester and are then converted into DC power using self-powered system interface. Along with the vibrations, the vibrations from TEG energy are pumped up and paralleled connected to other energy sources. This system produced greater than 1Volt output for higher than 100 kΩ load resistances. Energy optimization and cost analysis is still a challenge in the given model.

Khan, Wan, Syed et. al. (2018) presented a Super capacitor-Based HEH for Low-power system. This research gives an concept of a Maglev proposed system coupled to a microcontroller that can produce power and captures the energy in super capacitor using low velocity wind in rural areas. There were two limitations in this system firstly the propeller design was not considered. Secondly the DC/DC boost convertor wasn't working properly according to the data sheet mentioned. Designing of the buck/boost converter for the hybrid energy harvesting is still a challenge and is unattended area.

Cho, Lee, Hong et. al. (2018) designed energy harvesting system comprising of peak air stable quantum dots solar cells (QDSCs) and a Tribo Electric Nano Generator (TENG). With high potential and high photocurrent from TENG and QDCSs instant power and then constant increasing of power generation is achieved. Each component illustrated amazing energy

conversion specifications using various energy sources like mechanical vibrations, sound waves, wind, and sunlight. This proposed HEH harvests energy from mechanical vibration and photons. Also synergetic and complementary effects of the HEH were analyzed when all the energy sources are actively harvesting energy. The energy is obtained from the system and IR sensor of IoT is powered. Optimization of the hardware and algorithm is still a challenge of the design and is unattended area. Also there is deep investigation needed for the WSN systems.

Deng, Yue, Chen et. al. (2019) recommended a model which focuses more on efficient energy harvesting method considering a stagnant solar energy and other energy sources. Markov decision process (MDP) having cost function is employed to maximize the energy usage. With finite battery size and finite packet buffer, the MDP framework includes the actions set, the state transition probabilities, and the states space. This model was efficient for providing an best output for optimization of PDP and various energy harvesting from various system. The statistical models and MDP models can be validated by applying them on hardware and by analyzing the real system which is unattended area of the author.

Wang, You, and He (2013) presented hybrid energy system for autonomous devices. This model uses photovoltaic piezoelectric generators as the primary harvesters. A super-capacitor and battery are used for energy storage. This model proposed optimal mathematical solution and equations and changes the solar cells units and PZ generators, batteries and super capacitor for optimized energy harvesting. The General Coefficient Distribution Method is defined using distribution factors' combination as an energy management technique. By utilizing the hybrid storage structure the energy management can be improved in the hybrid energy harvesting. Hybrid energy storage includes the use of Super capacitor and battery. Advantages of both can be utilized in hybrid energy.

Lee, Kim, Hwang et. al. (2018) proposed a model which uses a Spherical Hybrid Tribo Electric Nano Generator (SH-TENG) that optimally gathers the energy from water waves of low frequency. This proposed system able to harvest energy using the kinetic energy of the water waves using single electrode. This SH-TENG shows good implementation of self-powered monitoring systems that access components such pollution levels in water bodies, water wave

height and water temperature. A capacitor is used for confirming that that solid–solid tribo electrification and solid–liquid tribo electrification are harvested using the dual sides of single electrode layer.

Yildiz, Gungor and Tavli (2018) developed an energy harvesting system by developing MIP(Mixed Integer Programming) framework using solar and electromagnetic energies. The proposed method takes into account the random nature of weather conditions. At the top of shadowing channel acting as the physical medium, the MIP framework is developed which deploy transmission of energy control on associated link. This proposed work is to minimize and analyze the energy utilization of the efficient energy WSN node. By this method the energy consumption of efficient energy using node is decreased up-to 81.40%. Using Artificial Intelligent (AI) the model can be more improved and can be consider as an unattended area of the hybrid energy harvesting.

Xu, Zhang, Han et.al. (2018) come up with a HEH scheme using magnetic field and mechanical vibrations simultaneously. The proposed model comprises of a magneto strictive substrate bonded with a piezoelectric sheet. The energy harvester investigates AC magnetic field and the phase change between the harmonic vibrations. When magnetic excitation and vibration have similar frequency, the phase difference will straightly influence the result of energy of the combined excitations whereas in the case of resonance output voltage is decided by stronger vibration. When compared with the magnetic and vibration excitations the power of energy harvester is increased by 14.82% and 30.40% respectively using intelligent algorithm the power may be enhanced by 5% in both the cases.

Toyabur, Salauddin, Cho et.al. (2018) proposed a multimodal hybrid PZ–EM energy harvester carved on vibration having various degrees-of-freedom. The multimodal has a different design that provides it to contain various resonant vibration modes in a particular frequency range. Higher output power is obtained using the PZ-EM hybrid system by minimizing resonance affect. The proposed system can work at 4 resonant vibration (12–22Hz range), which are focused around 22, 17, 15, and 12Hz. With 10Hz bandwidth all resonators provide output energy

simultaneously. There is phase difference between the voltages produced by different generators, so it is necessary to condition the generators before connecting them.

Shaharizal (2017) designed a different energy harvesting method called hybrid energy harvester based on Piezoelectric and Magneto strictive/Electromagnetic transducers which is integrated into a system. The model developed targets the higher output power using the vibration bandwidth's expansion in spite of the single energy harvesters. By using MATLAB we formulate the respective mathematical models for each transducer then simulations are done using MATLAB. Secondly, a prototype device is investigated from the experiments. Maximum voltage found is 6.23V @ 59.6Hz.

Rao and Mehta (2014) presented a energy harvesting method which provides an impressive solution for overcoming the issue of lifetime of WSNs. In this method, an investigation of the nodes energy consumption based on communication failures because of channel fading has been done. This directly affects the performance of WSN network. The author also investigated the issues of small life time of sensor nodes. The author provides lower bound and upper bounded framework over which the hybrid energy harvesting system can be deployed to have faithful quality of service.

Patil (2012) submitted a thesis describing an innovative system with rotation motion which has high energy density EM harvester device. The objective of the article is to have high energy extraction device using rotational motion. An autonomous rotational motion system has been investigated and deployed using the static magnetic field. The static magnetic field provide the current in the moving coil that is attached with the stator and energy is produced. A 50 mW/cm^3 of energy is produced and used for capturing in the battery and utilized for small scale electronics. The proposed schematic also helps in overcoming the problem of overheating otherwise it can damage the permanent magnets. It delivers 2.5W of power at 110Hz frequency.

Verma and Sharma (2018) gave a thermal energy harvesting system with efficient algorithm which is able to harvest 6kJ of energy in summer time and able to provide energy to WSN node. Author proposed solution to provide perpetual duration for WSN using the optimized framework for energy harvesting. The author used Phase Change Material (PCM) to invert the temperature

to increase the overall system efficiency. The system can be used with the solar system and thermal energy generation mechanism to better the duration of the WSN. Solar and thermal energy generation mechanism together can increase the reach of the energy harvesting for more geographical areas.

Verma and Sharma (2019) investigated Sb_2Te_3 and Bi_2Te_3materials for the efficient designing of thermal energy generating mechanism. The figure of merit and efficiency of the various types of bismuth telluride and tin telluride has been investigated and model of efficiency has been proposed. A hardware model is needed to validate the various expects as a research gap in this paper.

2.1 Gaps in Literature

Analysis of literature of the HEH has provided some of the important an unattended area in the field of energy generation. It's found that hybrid energy generation has the multiple sources, can be harvested for the energy harvesting and the energy harvested is captured by the buck/boost converter and Maximum Power Point Tracking (MPPT) Mechanism. The mechanism is also based on the energy cache device which is important to decide on the base of the source of hybrid energy harvesting system. Literature depicts that there is still scope of research in the domain of integration of the different sources. The unattended area of optimization of the framework of hybrid energy generation motivates to work over it. The design of efficient power management module for the hybrid energy producing is still a exception for the exploration community. This research gap in the low power consumption of algorithm design is also analyzed in the literature review. The storage technology for the integrated energy harvesting is still needed to explore in the future work. The WSN need a careful investigation of the energy management algorithm for the energy harvesting systems in which such algorithm need special attention for the hybrid energy harvesting technique.

3. DESCRIPTION OF BROAD AREA

Wireless Sensor Network (WSN) is made of many number of sensor node. One node consists of microcontroller, communication unit, Sensor to sense the physical quantity and one energy cache

unit like battery or Super capacitor. Energy harvesting system is also used with the WSN node which is used to gather the energy through natural means. Duration of the sensor node can be improved through the use of the energy harvesting technique. There are many natural and man-made energy sources which can be harvested from the surrounding as from Thermal, Solar, Piezoelectric, wind, Acoustic, Mechanical etc.

Solar energy harvesting need solar light. Solar light fall on the Photovoltaic (PV) cell which converts the visible band of the solar energy to the electrical energy. The resultant electrical energy has constant potential difference (Open Circuit) while the current may vary according to light condition for this a DC-DC voltage converter is used which is able to provide constant output voltage.

Thermal energy gathering is used to gather energy through temperature differences. The temperature difference converts to electrical energy through Peltier's effect. The main challenge in thermal energy harvesting is to continue the temperature difference across thermoelectric generator. The temperature difference can be obtained by efficient thermal conducting mechanical design in which the temperature flow from hot to cold can be obtained perfectly.

Similarly, the mechanical energy harvesting, wind energy harvesting uses the piezoelectric transducers to convert mechanical energy into electrical energy. RF energy harvesting provides least output energy among all kind of energy sources. In this energy harvesting the RF waves converted into electrical energy using the high frequency detecting diodes.

Harvesting energy from single source has their own limitation. Solar energy harvesting unable to harvest the energy in the forests area, thermal energy harvesting unable to harvest energy at low temperature areas, similarly mechanical energy is difficult to harvest where mechanical movement is considerably low.

For such cases we need to develop the hybrid energy harvesting where energy can be harvested from multiple sources. The application is WSN where the form factor plays important role. The size of the hybrid energy harvesting must be small so that it should clear the criteria of small size and can be fitted into sensor node.

4. OBJECTIVES OF RESEARCH

The research objectives are framed on the basis of the problems that have been identified in the literature survey.

4.1 Problem Formulation

Prolonging Lifetime of WSN is one of the major area of interest because of wide area of application of WSN. The issue is overcome by the method of Energy harvesting from different renewable or non-renewable energy sources. The Energy harvesting can be done in many ways like solar energy, Wind energy, acoustic, Vibrational etc. But these methods cannot be used without the presence of natural resource e.g. if solar light is not present than the energy could not be drawn. This is also has been analyzed that single kind of energy sources may not appropriate considering the perpetual duration of sensor node. This is the major reason due to which the attention has been drawn to hybrid energy harvesting. The hybrid Energy harvesting in WSN provides energy on demand and is very useful for the various applications to better the duration of the node. So far from literature review it has been seen that lot of work has been done to better the energy efficiency of WSN. The work has been predominantly focused on Network layer, MAC layer application layer and physical layer and energy management and energy harvesting systems. The following problems have been identified for Hybrid Energy Harvesting in Wireless Sensor Network (HEHWSN):

1. **Efficient Hardware:** Efficient hardware design is still a challenging task for HEHWSN because of unattended area. The hardware must provide high efficiency so that more power can be generated.
2. **Data Processing and Harvesting:** Protocols should be developed to process data and HEH simultaneously.
3. **Efficient Algorithm Design:** Efficient Algorithm design is still a challenge which can optimize the energy harvesting more than one energy source. There is still a lot of work needed due to unattended area of algorithm optimization, dedicated for the efficient algorithm for hybrid energy harvesting for perpetual life time of WSN nodes.

4.2 Objectives

The objectives of work in the field of Hybrid Energy Harvesting to enhance the lifetime of WSN are as follows:

1. To study and Analyze existing energy harvesting systems and investigation of hybrid energy harvesting systems.

2. To optimize hardware models to enhance the overall efficiency of hybrid energy harvesting system for WSN application.
3. To propose an optimized framework for hybrid energy harvesting system to enhance duration of WSN.

5. METHODOLOGY

The research has been divided into three phases:

PHASE 1

Study

The existing designs will be investigated and analyzed using the MATLAB tools. The results will be investigated. Different types of materials also investigated for the solar cells and thermal energy harvesting system. Parameters for solar cell as well as thermal energy harvesting will be found and listed. Some of the parameters will be encountered to improve at system level.

Investigation of Existing Energy Harvesting Structures

As discussed above that the energy harvesting needs a converter to convert one form of energy to electrical energy. Solar energy generation and Thermal energy generation may provide better results for environmental monitoring. So the study is focused on these two topics. It is found in the literature that the research community is using Advanced Design System (ADS) and MATLAB software tool for the implementation of solar energy harvesting circuits. Thermal energy harvesting is majorly analyzed over the MATLAB simulation. The circuits and techniques implemented by the research community are verified using the same tools. In this research work, the same tools have been used for the designing and implementation purpose.

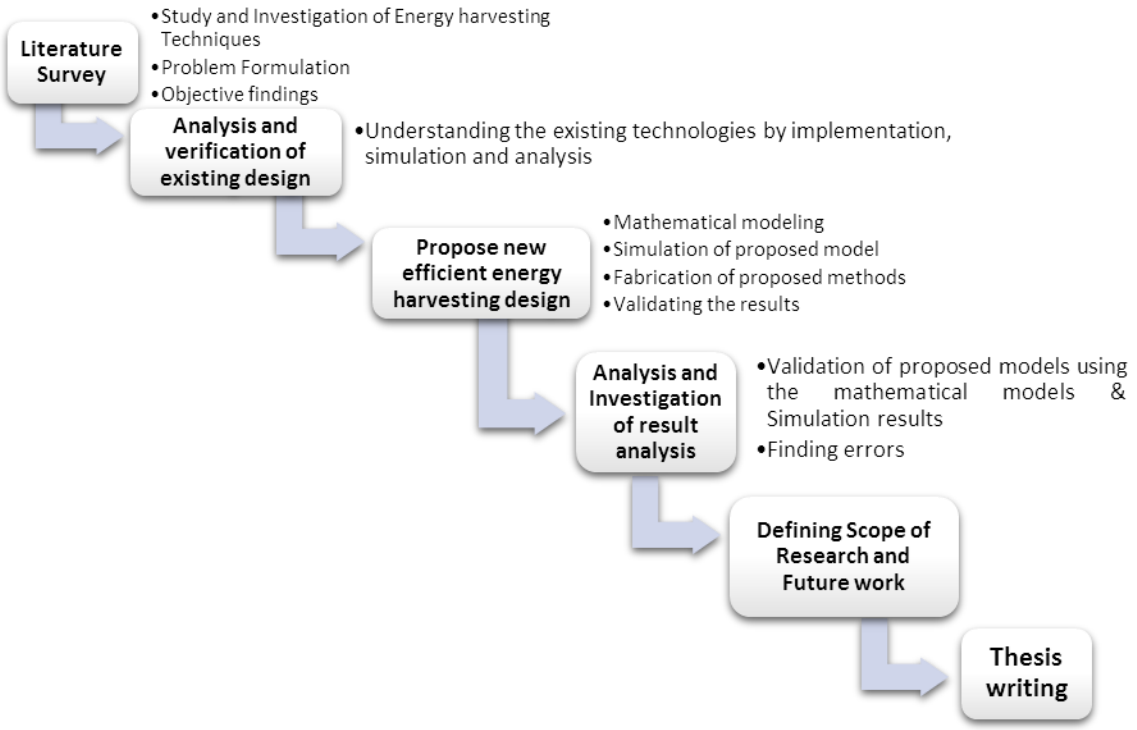
Literature Survey
•Study and Investigation of Energy harvesting Techniques
•Problem Formulation
•Objective findings
Analysis and verification of existing design
•Understanding the existing technologies by implementation, simulation and analysis
Propose new efficient energy harvesting design
•Mathematical modeling
•Simulation of proposed model
•Fabrication of proposed methods
•Validating the results
Analysis and Investigation of result analysis
•Validation of proposed models using the mathematical models & Simulation results
•Finding errors
Defining Scope of Research and Future work
Thesis writing

Figure 3: Flow diagrams

PHASE 2

New Framework of Hybrid Energy Harvesting for WSN

On the basis of gathered knowledge and research gaps, a new framework will be proposed. The proposed architecture is designed and implemented with the help of the above-said tools. This will be tried at the best that the designed architecture is optimized for WSN environmental applications. Energy harvesting in environmental monitoring is implemented and optimized for hybrid of two types of design. Solar energy harvesting and thermal energy harvesting with new design will be investigated.

Developing an Efficient and Optimized Structure

The suggested design will be modeled, produced and analyzed with the use of the software tools. The Simulink is used to design and investigate the solar energy generation circuit and MATLAB will be used for the Thermal energy generation modeling of a figure of merit. An algorithm for the smooth operation of thermal energy harvesting will be also developed and implemented in the design which increases its overall output power and made this design suitable for WSN environmental application.

Implementation and Fabrication of Design

The optimized design will be implemented and fabricated for the result validation.

PHASE 3

Result Observation

Obtained results from the designed units will be analyzed and observed. The results from simulation experiments will be investigated.

Details of proposed methodology, work flow and tools have been mentioned in Fig. 4.

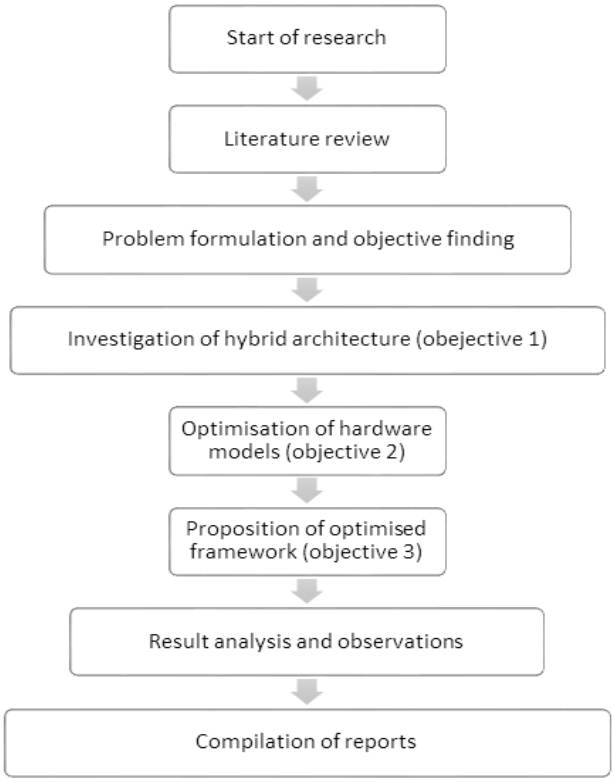
Start of research
Literature review
Problem formulation and objective finding
Investigation of hybrid architecture (obejective 1)
Optimisation of hardware models (objective 2)
Proposition of optimised framework (objective 3)
Result analysis and observations
Compilation of reports

Figure 4: Methodology

6. EXPECTED OUTCOME OF THE RESEARCH

Hybrid energy generation (HEH) reaches as mentioned and focused on various power management schemes to generate multiple energy resources. The model for possible combination

of the hybrid energy harvesting is proposed as solution. The efficiency achieved by the complete hybrid energy model may provide perpetual lifetime. Comparison of conventional and proposed techniques for different hybrid energy model configurations will be done if approximate model found in the existing work. Two sources best suited for the hybrid energy harvesting for the environmental monitoring in WSN will be implemented. The implemented framework will be able to provide the nearly perpetual life time to the sensor node. The optimized framework for hybrid energy harvesting along with intelligent algorithm may provide new paradigm for WSN node perpetual lifetime.

7. PROPOSED TIME FRAME

Time frame	Sept. 2018 - June 2019	July 2019 - Dec. 2019	Jan. 2020- June 2020	July 2020 - Dec. 2020	Jan. 2021 - June 2021
Course Work					
Literature Survey					
Review paper based on Literature Survey to achieve Objective 1					
Base paper Implementation for achieving Objective 2					
Objective 3					
Compilation of Work: Thesis Writing					

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